Image correlation analysis를 이용한 종이의 재료 역학적 특성에 관한 연구 III

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1. Introduction

The use of finite element software for the solution of mechanics problems involving paper materials requires that the user provide input regarding the elastic constants in an elasticity analysis or a specialized constitutive model when the problem requires taking inelastic aspects into account. In the case of elastic behavior, assuming a plane stress analysis, there are four in-plane elastic constants that must be specified in order to characterize the paper material for analysis. In many situations information regarding all four constants is not available and it is necessary to estimate appropriate values for some of the constants. The elastic constants of any paper material depend on a variety of physical factors related to the internal structure of the material.

The network structure is characterized by a variety of nonuniform characteristic attributes into the network structure, it is necessary to address the micromechanics problem from a numerical point of view. It is not feasible to develop closed-form relations under these circumstances. On the other hand, with the power of the desktop PC, it is feasible to approach some of these modeling features by a numerical solution of the equations for typical fibers.

Numerical solution of the micromechanics equations can be broken down into those methods that model the fiber as a continuous system and solve the equilibrium equations by numerical ordinary differential equating solvers, and into those methods that model the fiber using the techniques of finite element analysis. The information obtained form the predicted macroscopic stress-strain behavior of the paper can be used as the user input information that is necessary in using commercial finite element codes such as ABAQUS or ANSYS that provide for user input of specialized constitutive behavior. Examples of this type were provided in the literature [1-5].

Overall objective of this study is to investigate how paper behaves when in-plane loading is high enough for non-linear effects. Strain components around the circular hole (especially along lines leading from the hole edge along the longitudinal and lateral axes), will be obtained using image correlation analysis at several load levels to provide a data set for finite element analysis.

2. Material and method

2.1 Material

The paper material selected for this study is a greeting card paper. This paper has a basis weight of 122 g/m^2, a density of approximately 676 kg/m^3, and exhibits a strongly anisotropic and nonlinear behavior. Liner has been also used for measuring the nature and extent of damage that takes place around the hole preceding failure.

2.2 Digital camcorder

A SONY DCR-TRV 730 digital video camera recorder was used to acquire digital images of the surfaces of undeformed and deformed paper specimens. The use of the digital camcorder is advantageous, since it eliminates the need for a frame grabber option that converts the camera signal from analog to digital form for computer processing. In practice, the digitizing process can cause the gray-value at any pixel to vary from image to image as the frame grabber converts the camera signal from analog to digital form.

2.3 Image correlation software

VIC_2D (Beta 3.0.3 version) image acquisition software developed at the University of South Carolina was used. The digital camcorder was set up approximately 152.4 cm from the specimen in order to compensate for any "out of plane motion" of the specimen. This gave a field of view of approximately 4 square inches at the maximum zoom-in of the digital camcorder. A standard photographic tripod was used for a camera mount in this research. Special care was taken to ensure that the image plane of the camera was exactly parallel with the test specimen surface.

2.4 Testing machine

All experiments were carried out using a 50kN capacity Instron Model 4204 electromechanical universal testing machine. This machine is designed for testing materials in tension, compression, shear, and flexure from 0.1 N to 50 kN. The test machine is composed of loading frame components and control console components. The Model 4204 incorporates a microprocessor controlled, closed-loop, and servo drive system with an optical encoder feedback assuring accurate and constant crosshead speed. Thus speeds are independent of the voltage, frequency, or applied force (with rating).

2.5 Finite element analysis software

UMAT option in ABAQUS was used to make a model for the case of a central holed paper material. The model incorporated nonlinear fiber and bond behavior as well as nonuniform characteristics of the fiber and bonds as a function of position along the mesoelement. Furthermore, the model was capable of incorporating differences between compressive and tensile response at the mesoelement level. Of course, this aspect appears to be an important properties of constitutive models for paper since experimental evidence suggests very significant differences in planar sheet response for compressive and tensile loading.

3. Results and Discussions

Figure 1 is the schematic diagram for a typical test set-up, which includes an Instron Model 4204 universal testing machine, digital image measurement system, and related post-processing computer. There are two main parts: load mechanism and full-field measurement with the image correlation system.

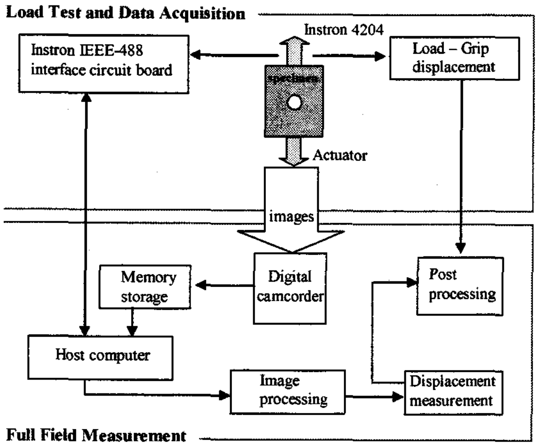

Figure 1. Schematic representation of the experimental set-up.

The calculated distribution for the stress component s_{11} is shown in the contour plot of Figure 2.

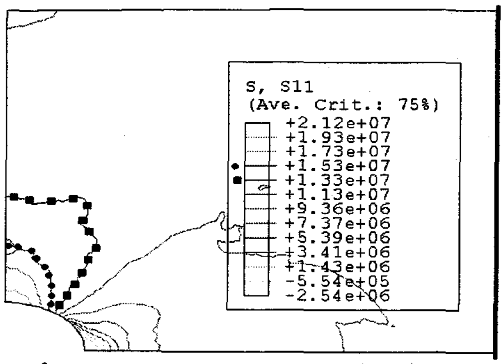

Figure 2. Contour plot of stress component s_{11} (S11) near the hole surface. CD loading for sample width of 4.3 cm at the failure point.

The results show that good comparisons are obtained as long as the axial loading is sufficiently low that the strain does not exceed the failure limit at the hole surface. This is the case for loading level 1 corresponding to an apparent strain level of 0.89 percent strain as shown in Figure 3.

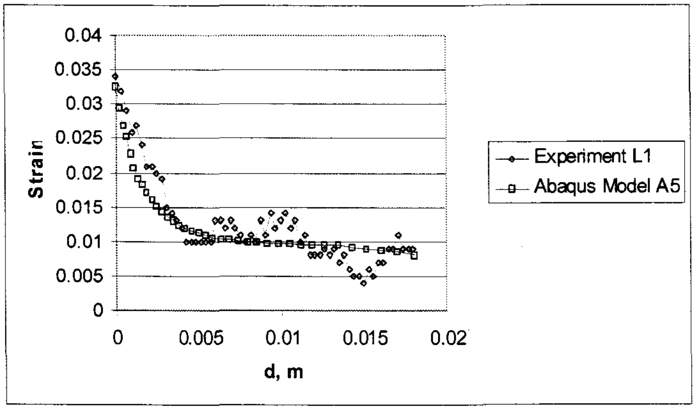

Figure 3. Strain component e_{11} along the $x_2$axis, d represents distance from the hole edge. CD loading at apparent strain level of 0.89 percent. Sample c10, subset size 30 and step size 5 pixels.

For purposes of estimating the zone of damage extending along the x_2 axis is it advantageous to inspect the path plot for the stress component s_{11} along x_2 which is shown in Figure 4. Figure 4, in fact, shows the path plots at the three sample widths of 1.6, 4.3 and 8.9 cm.

The point-stress criterion for failure requires that the intersection of the uniaxial strength curve and the simulated stress curve should take place at the same value of the distance from the hole surface, d, regardless of sample width. It is observed in the case of the CD loading (Figure 4) that the 8.9 cm width and the 4.3 cm width curves intersect the uniaxial strength curve at the same point which is for the value of d equal to about 6 mm. On the other hand, the 1.6 cm curve intersects the strength curve at a smaller value of d equal to about 3 mm.

4. Conclusion

The results of the simulations show that there is a region extending outward from the hole surface along the $x_2$axis where the stress has exceeded the strength of the material. This leads to the expectation that there is extensive damage in this region that precedes the load corresponding to catastrophic failure of the holed sample. In the context of the point- stress criterion, the damage region appears to be on the order of 3 to 6 mm from the hole surface. This finding is not at variance with the results reported by Kortschot and Trakas [6].

The procedure of simulation of the failure of the holed samples should probably be considered from a more probabilistic point of view. In the simulations above, we have used the average values of the apparent strain at the point of failure. Furthermore, the constitutive model is based on the average stress-strain curve. The actual stress-strain curve varies from sample to sample and also the failure point for the holed sample is subject to variation from sample to sample. Even the process of making the hole in the paper may lead to variable damage at the hole surface.

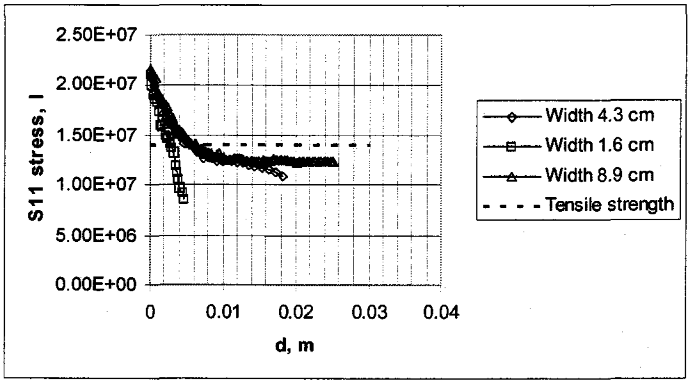

Figure 4. Stress component s_{11}(S11) versus distance from the hole surface (d) along the x_2 axis. CD loading at the failure point forthree different sample widths.

5. References

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